Using Penetrometers to Measure Sea Bed Properties

Robert D. Stoll
Lamont-Doherty Earth Observatory of Columbia University,
Palisades, N. Y. 10964
phone: (845) 365 8392 fax: (845) 365 8179 email: stoll@ldeo.columbia.edu

Y.-F. Sun
Lamont-Doherty Earth Observatory of Columbia University,
Palisades, N. Y. 10964
phone: (845) 365 8504 fax: (845) 365 3182 email: sunyf@ldeo.columbia.edu

Award #: N00014-01-1-0275

LONG-TERM GOAL

The long-term goal of this work is to develop a set of tools that can be used to determine *insitu* values for certain sediment geotechnical properties that are needed to predict the potential for burial when various objects such as mines impact the sea bottom.

OBJECTIVES

The principal objective of this work has been to develop a set of mechanical, remote-sensing tools that will permit the determination of the main geotechnical variables that control mine burial in the bottom. These variables include the shear strength of both soft, fine-grained sediments and coarser, dilative granular sediments. A further objective is to understand better the response of typical near-shore deposits composed of layered fine and coarse sediment.

APPROACH

Over the past several years our field work has led to the development of a number of remote-sensing tools that have direct application to the problem of mine burial prediction. As an example, the penetration resistance measured by several different types of probe that we have developed is directly related to the bearing capacity of the sediment which is of prime importance in studies of mine burial in the seafloor. These probes include XBP, an expendable bottom penetrometer, PROBOS, a modified version of the Canadian STING penetrometer and a quasistatic penetrometer, STATPEN, that measures both cone and sleeve penetration resistance to a depth of 2 meters into the sea floor. The XBP probes have been used to map critical areas in recent NATO exercises aimed at "Rapid Environmental Assessment" (Stoll and Akal, 1999) and various versions of STATPEN have been built for NATO, Saclant Undersea Research Centre and for the Naval Research Lab, Stennis Space Center.

STATPEN utilizes a cone penetrometer of standard size and shape (i.e. Amer. Soc. Testing and Materials (ASTM) std 60 degree cone, 10 square centimeters of cross-sectional area and a 2 cm/sec penetration rate) supported by a weighted, 4-legged frame that rests on the sea bottom during deployment of the cone. The penetrometer frame is first lowered to a depth about 1or 2 meters above the bottom to allow temperature and pressure transients to dissipate and then lowered the rest of the

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2005**	2. REPORT TYPE	3. DATES COVERED **00-00-2005 to 00-00-2005**

4. TITLE AND SUBTITLE **Using Penetrometers to Measure Sea Bed Properties**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Lamont-Doherty Earth Observatory of Columbia University,Palisades,NY,10964**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT
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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

way at test time. Our basic unit is capable of pushing the cone to a depth of 2 m with a maximum thrust of 1000 lbs. The unit is easily dismantled for shipping and has been used in the Mediterranean and the Baltic for “ground-truthing” a number of acoustics experiments and in the waters around New York Harbor to measure the thickness of sand caps over dredge spoil areas. Because of the wealth of data available in the literature for tests performed with a standard ASTM cone penetrometer, in most cases, undrained shear strength for fine-grained cohesive sediment can be directly estimated from the cone resistance using various correlations that have been published.

STATPEN being lowered with CTD winch and PROBOS being hand launched

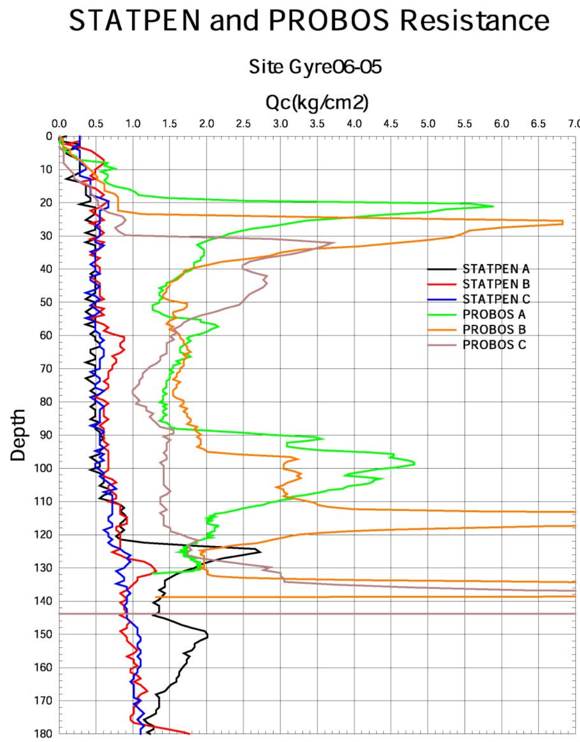
PROBOS is an improved version of the Canadian “STING” penetrometer with the same dimensions and shape as the STING but with additional capability of being able to display both the force on the tip as well as the deceleration of the unit without the necessity of recovering the probe and downloading the data with each deployment as is the case with the STING.

XBP is a system using expendable probes of the same size and shape as the standard XBT (Expendable Bathythermograph). However in the XBP, instead of temperature measurements in the water column, deceleration is measured during impact and penetration of the bottom and this data is then integrated to determine depth of penetration and the penetration resistance of the sediment. The characteristics of the impact signature are then analyzed to obtain shear strength, sediment type and other properties based on a large data base that has been collected over the past few years at SACLANT Center and Lamont-Doherty Earth Observatory (Stoll and Akal, 1999). While the penetration depth of these small units is limited they have a big advantage in that all of the variables that control penetration such as terminal velocity and trajectory are largely independent of water depth so that data is easily correlated with strength properties.

WORK COMPLETED

We have participated in two mine burial cruises in the gulf of Mexico near Corpus Christi, Texas, Gyre 10 (01) in October 2001 and Gyre 06 (02) in May 2002. STATPEN, XBP and PROBOS were

deployed during both cruises. During FY03 analysis of the records from these deployments showed that there was a considerable amount of heterogeneity in the sediment at a number of the sites chosen for mine-drop experiments and that the response of the sediment varied significantly when comparing the penetration resistance during slow and rapid penetration. As an example the results of several STATPEN and PROBOS deployments at the same location are shown in the figure below. While the STATPEN results from slow penetration show a relatively uniform resistance (left hand three curves), the PROBOS results, obtained with the probe contacting the bottom at several hundred cm/sec, indicate significant variations in resistance with high peaks in several locations. We attribute these peaks to dilative behavior in granular layers.

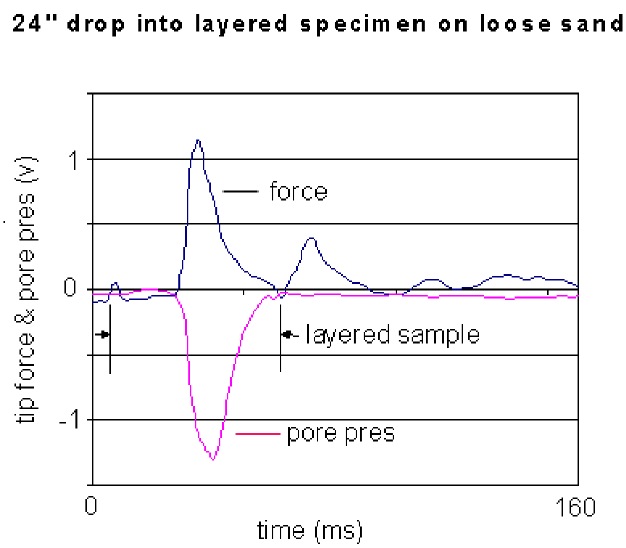


STATPEN and PROBOS Tip Resistance from Gyre 6, Site 5 plotted to same scale. Depth is relative to mudline. Peaks in the PROBOS data at about 30 cm depth are attributed to dilative behavior of granular layers at that depth.

During FY04 and FY05 we performed a number of laboratory experiments wherein PROBOS was pushed at various rates into a tank filled with water-saturated sand in order to verify the nature of this kind of dilative behavior. These tests clearly indicated that rapid penetration into a granular sediment can result in sudden high resistance to penetration due to sudden decreases in pore-water pressure from dilation near the rapidly moving tip of the probe. Additional tests on a layered sediment wherein a thin layer of sand was sandwiched between clay strata, also demonstrated the effects of dilative behavior. The experimental setup for the layered experiments and some recent results are shown in the figures below.

RESULTS

Results of the tests performed during the GYRE 10 and 06 cruises have been described in two preliminary reports (Stoll, Sun and Bitte, Nov. 2001 and Stoll, Sun and Bitte, Jul, 2002) and a more detailed report (Stoll, Sun and Bitte, Jun 2003). In addition, numerical and graphical results were posted for electronic downloading on the ONR Mine Burial Web Site. Based on the information in these reports a paper was presented in Baltimore in October 2004 at the ASCE conference "Civil Engineering in the Oceans, VI" (Stoll, 2005) and a paper (Stoll, Sun and Bitte, 2006) has been submitted for inclusion in a special issue of the IEEE Jour. Of Oceanic Engineering that is being edited by guest editors R. Wilkens and M. Richardson.



PROBOS penetration of clay-sand-clay specimen resting on a tank of saturated sand. Tip force and pore pressure near tip in layered specimen are shown in right hand record.

IMPACT/APPLICATION

By running both quasi-static (STATPEN) and dynamic (XBP and PROBOS) penetration tests at most of the test sites we have developed a data base that allows the following studies to be made:

1.Estimates of insitu shear strength – based on correlation with quasi-static penetration resistance.

2. Estimates of strain-rate effect – based on comparisons of STATPEN and PROBOS penetration resistance at various depths in the sediment column.

To date our analysis of the field data has revealed a number of factors that have an effect on our ability

to correctly predict the impact burial of mines and other objects. Moreover the kind of response seen in the figure above (STATPEN and PROBOS Resistance) cannot be handled by any of the mine burial programs in common use. Hence it appears that work needs to be done to define more realistic and flexible algorithms for inclusion in the mine burial programs so that layered sediments with both granular and cohesive components can be modeled properly.

TRANSITIONS

We prepared an XBP evaluation package for the Naval Oceanographic office composed of software, an electronic interface board and a user's manual for use on board NAVO ships. As a result of their initial trials of the XBP they ordered eight addition systems for use on their survey vessels and on Navy mine hunting ships. We have also supplied NAVO with an upgrade that allows XBPs to be launched by a single technician. We have built modified versions of the STATPEN for NATO, Saclant Undersea Research Center and the Naval Research Lab, Stennis Space Center.

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